Emerging Energy Sources' Social Acceptability: Evidence from Marine-based Energy Projects.

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Abstract: Any decrease in global warming and its effects can only occur with a substantial reduction in anthropogenic CO_2 emissions. In this context, renewable energy sources, particularly emerging sources, may play a central role in accelerating the transition from fossil fuels to cleaner energy sources. Emerging energy sources are renewable and have the potential to reduce global warming emissions; however, they are in the early development stages. These technologies include enhanced geothermal processes, artificial photosynthesis, and marine energy. In this study, we assess the main attributes that determine the social acceptance of renewable marine energy projects, highlighting individual preferences and heterogeneity for these projects. The results show that energy generation, ecological impact, job creation, co-ownership, and distributional justice are statistically significant attributes that support projects. However, individual preferences are highly heterogeneous. The existence of distinct classes (two in this case) with different preferences for marine energy attributes indicates that the one-size-fits-all approach may be inappropriate. Instead, policymakers and energy producers should tailor their proposals to meet the needs of both groups, considering their preferences and concerns.

Keywords: Social Acceptance, Community Acceptance, Marine Energy, Emerging Energy Sources, Choice Experiments, Latent Class.

Highlights

- We assess the main attributes determining the social acceptance of marine energy projects.
- We highlight individual preferences heterogeneity for marine projects.
- We found that co-ownership and distributional justice affect a project's social acceptance.
- We found two distinct classes with different preferences for marine energy attributes.

Word Count: 8,110

Nomenclature

Abbreviations:

- CO2: Carbon dioxide
- RES: Renewable energy sources
- MES: Mainstream energy sources
- EES: Emerging energy sources
- SA: Social acceptance
- DCE: Discrete choice experiment
- MNL: Multinomial logit
- LC: Latent class
- CV: Contingent valuation
- R&D: Research and development
- WTP: willingness to pay
- NES: National Electric System
- MW: Megawatt
- MERIC: Marine Research and Innovation Center
- USD: United States dollar
- NCRES: Non-conventional new renewable sources
- RUM: Random utility model
- IID: Identically and independently
- SQ: Status quo
- SQS: Status quo supporters
- EESS: Emerging energy sources supporters
- MWTA: Mean willingness to accept

Symbols:

n: individual

i: chosen alternative

J: Total set of alternatives.

V_{in}: utility function deterministic and observed component

ε_{in}: utility function stochastic and non-observable component

Q: finite set of latent classes

$\pi_{n,q}$: probability individual n of belonging to class q.

β_q: individual common parameters within the class q.

z_n: sociodemographic variables to the class allocation.

x_{ikn}: k different attributes presented in the discrete choice model.

1. Introduction

Substantially reducing anthropogenic CO_2 emissions is the only solution to decreasing the effects of global warming. Moreover, limiting global warming to 1.5ºC requires reducing emissions by around 40% from 2010 levels by 2030 and reaching zero emissions by 2050. However, relaxing this target to less than 2ºC implies a reduction of 25% by 2030 and zero emissions by 2070 [1]. Any of these targets will require significant emission reductions sooner rather than later. Although anthropogenic CO_2 emissions have several sources, the leading source, accounting for approximately 80%, is the burning of fossil fuels [2]. Furthermore, the energy sector has intensively used fossil fuels, accounting for approximately 80% of the emissions in 2018 [3]. Thus, reducing CO_2 emissions to a level consistent with 1.5ºC requires decreasing this share. In this context, renewable energy sources (RES) are expected to accelerate the transition from fossil fuels to cleaner energy sources [1].

RES are sources that can be used repeatedly, have potentially no or reduced environmental impacts, and almost no emissions [4]. Recent estimations show that RES helped avoid approximately 25% of energy sector emissions in 2018, mainly owing to the transition to RES led by Asia and Europe [3]. Despite this, reaching an emission level consistent with the 1.5ºC goal will require the consideration of other RES sources to increase the spectrum of alternatives and accelerate the energy transition to make this global objective possible. This study assesses the social acceptability of new renewable energy sources, focusing on the perceived barriers hindering energy development.

According to [4], RES can be classified as mainstream energy sources (MES) and emerging energy sources (EES). MES are renewable sources that are currently integrated into energy systems at the industrial level, such as, solar, wind, or hydropower. Contrastingly, EES are renewable sources with the potential to reduce global warming emissions, but they are in earlier development stages. These technologies include enhanced geothermal energy, artificial photosynthesis, and renewable marine energies.

Renewable marine energy sources include alternatives such as offshore wind, wave, and tidal energy. However, this process is in the early stages of development. The sector is booming. On the one hand, the offshore wind sector has experienced exponential growth over the past decade, initially growing in Europe and subsequently expanding to North and South America, Asia, and other regions, with 2022 as the second-best year ever for the global offshore wind industry [5]. On the other hand, wave and tidal energy technologies remain nascent, with their short-term contributions to renewable energy objectives considered minimal but with tremendous transformative potential for the energy sector [6]. Marine energy generation is essential owing to its widespread applicability and stability [7].

Moreover, marine energy is ranked fourth in terms of global technical potential behind biomass [4,8]. Despite the transformative potential of marine energy sources, there are challenges to address in terms of potential opposition from different stakeholders [9], including other users of marine areas (i.e., fishermen) or the general public, in light of environmental, social, or economic impacts [10]. Thus, we need a better understanding of stakeholder's attitudes toward marine energy, which will eventually define the degree of acceptance of this type of project.

The social acceptance (SA) of energy sources is a critical factor in successfully developing and managing new energy technologies, such as EES [11]. SA is associated with the amount of project support (active or passive) provided by different stakeholders [12]. According to [13], SA is a three-dimensional market, socio-political, and community acceptance construct. SA has become a prominent study area for nonrenewable and renewable energy sources, mainly driven by environmental concerns about new or existing technologies. For instance, by assessing the SA of a new fossil fuel infrastructure [14], or analyzing the SA of hydraulic fracturing projects [15–17]. Furthermore, the level of SA of energy projects can differ among individuals within the same area. Some examples of this heterogeneity have been found in wind generation [18,19], solar, and biomass projects [20].

In this study, we assessed the main attributes that determine the SA of renewable marine energy projects, highlighting the heterogeneity of individual preferences for these projects. Primarily, we wanted to determine whether more significant and diverse degrees of distributional justice could compensate for the perceived adverse effects of energy project development. Further, we innovate the mainstream literature by analyzing two dimensions of distributional justice: individual and social. We conducted a Discrete Choice Experiment (DCE) based on an online survey to identify the attributes that could hinder or foster the SA of tidal energy projects. We estimated two models: multinomial logit (MNL) and latent class (LC). We found that energy generation, ecological impact, job creation, co-ownership, and distributional justice were relevant elements for supporting a project. However, individuals' preferences are highly heterogeneous, and if we do not explore this heterogeneity, we can exclude a relevant part of the stakeholders' preferences. Chile was used as the case study. Chile has enormous potential for developing marine energy projects because of its long coastline along the Pacific Ocean. Further, during the previous few years, the country has conducted a series of regulatory changes to increase the share of RES in energy.

The literature on SA of RES is vast [21]. Some studies have assessed the SA of RES without distinguishing between particular technologies [22,23]. Some studies compared SA among a set of technologies [24]. Many studies on SA assessment related to specific RES have focused on wind energy [25–27]. In contrast, few studies have assessed SA in other mainstream RES such as solar [28,29], bioenergy [30], and hydropower [31].

Regarding the methodological approach used for SA analysis in RES, several studies have used opinion polls, whereas few studies have used surveys based on sophisticated questionnaires. Poll-based studies conduct simple statistical analyses to describe their findings based on questions about perceptions or opinions about RES in general or to evaluate a particular technology [21,32,33]. Regarding survey-based approaches, several studies have relied on stated preference methods to assess the attributes that determine the SA of RES. For instance, [23] used contingent valuation (CV) to analyze Poland's green energy SA. [23] conducted a similar study to assess renewable energy sources in South Korea. DCE has also been used to determine SA in RES. For instance, [34] uses DCE to evaluate the public preferences for solar, wind, and gas energy sources under different institutional and site-specific conditions in Switzerland. Similarly, [35] used a DCE to evaluate the SA of hydropower projects in Switzerland, and [36] studied the SA of small-scale solar photovoltaic plants in South Korea. [37] used the DCE to assess the public and local acceptance of an energy transition policy in South Korea. Readers interested in the willingness to pay for RES, mainly using CV, can find more information in the extensive reviews developed by [38] and [39].

Unfortunately, the evidence on SA of EES is scarce, and most studies are poll-based or qualitative. For instance, [40] conducted a survey in 12 Mediterranean cities aiming to identify the level of knowledge of marine energy and the willingness to host one or more marine energy facilities. According to their results, only 42% of respondents indicated familiarity with these technologies. Despite low awareness, there is significant openness to these technologies, with 70% of the participants expressing willingness to install marine energy in their local areas. [41] conducted a poll in two nearby villages in Northern Ireland affected by the development of a tidal energy converter, and found that place attachment positively affects project acceptance. Similarly, [42] found that positive beliefs about project benefits are related to project support. In contrast, [43] used a poll-based study to investigate attitudes and support for tidal energy technology by Washington state residents in the US. The study found strong acceptance of this technology among residents with higher perceived benefits or climate change beliefs. Furthermore, using a qualitative approach (12 in-depth interviews), [44] identified attributes that could foster (attract professionals, use local renewable energy, and promote regional research and development (R&D) activities) and hinder (the technology has not reached maturity, environmental impact of the facility, and limited yield) the SA of an oscillating water column shoreline plant in Spain. Similarly, [45] used a CV study in Washington state to elicit residents' willingness to pay (WTP) for tidal energy R&D. The authors found that potential risks and benefits are highly correlated with WTP. Finally, [46] used a DCE to study the construction of a tidal plant on the west coast of South Korea, while [47] investigated public perception and the monetary value of externalities associated with a tidal stream farm in Spain.

2. Literature Review

2.1 Social Acceptance and Energy Projects Development

According to [13], SA is a three-dimensional market, socio-political, and community acceptance construct. Market acceptance, mostly independent of the broader SA picture, describes the will of a market to adopt innovation or technology, for example, by reducing barriers to its diffusion. Socio-political acceptance addresses the superordinate level of SA and, hence, the general societal perception of innovations, policies, and technologies. For instance, many renewable energy projects are perceived as positive at the superordinate level. However, moving from general to project-specific site conditions, it must be acknowledged that problems that are challenging for the local population and reduce locally prevalent SA can arise. The third dimension of SA is community acceptance. This refers to the local stakeholders' specific acceptance of projects and project-related decisions at their sites, particularly by residents and local authorities.

Community acceptance has three determinants: procedural justice, which means having a fair say and the option to participate in the planning process; trust towards stakeholders; and distributional justice, referring to the allocation of costs and benefits. These costs can include both monetary and non-monetary factors, such as flora, fauna, and landscape changes, whereas the benefits can be tangible (e.g., revenue from power generation) or intangible (e.g., contributions to the local community, low-carbon energy supply). This study primarily focuses on distributional justice. We wanted to determine whether more significant degrees of distributional justice could compensate for the perceived adverse effects of energy project development. The evidence suggests that a high degree of distributional justice could have positive impacts on the SA of renewable energy projects, either through the provision of facilities for public use [48,49], a decrease in energy bills [50,51], job creation, [35,52] or benefit sharing [53].

2.2 Drivers of Community Acceptance

Similar to other energy sources, SA can hinder or foster the development of EES [11]. Unfortunately, there is limited evidence on the main SA drivers of EES, because most scholars have focused on MES [31]. To provide a robust foundation for our study, we conducted a thorough review of the studies that evaluated SA using DCE, considering EES and MES. Initially, we identified 48 articles spanning 2009 to 2022 that analyzed SA in a broad sense. We then categorized our article sample according to the analyzed SA constructs. The most studied construct is socio-political, with 30 articles, followed by community acceptance (11 articles), market acceptance (six articles), and one article jointly assessed socio-political acceptance and community acceptance within the same exercise [53]. Furthermore, the analysis revealed that wind, solar, and hydropower were the primary energy sources analyzed in terms of SA. Only two papers have analyzed community acceptance of tidal energy sources [46,47]. For our in-depth review, we selected 12 papers: 11 papers assessed community acceptance and one jointly assessed socio-political and community acceptance. Table 1 presents the main characteristics of these studies, including the energy sources, attributes used, countries, and energy mixes. The latter is included because previous evidence suggests that it plays a role in shaping individual preferences [37].

Our review found that the attributes used to assess community acceptance can be grouped into technological, ecological, socioeconomic, ownership, distributional justice, and procedural justice. These categories were independent of the energy sources. Using this categorization, we found that [54], in their analysis of the local acceptability of wind energy in Greece, used wind farm size as a technological attribute, differentiating among small, medium, large, and larger. Ecological attributes are related to farm installation (in or out of a natural protected area). By contrast, the distributional dimension is captured by a subsidy in the electricity bill at the household level. [52] analyzed the SA of on-shore wind energy in the Apulia region of Italy. In this case, technological attributes are represented by farm capacity. Ecological attributes include aesthetic impacts and CO_2 emission reductions. By contrast, the socioeconomic sphere is captured through the number of jobs created, whereas distributional justice includes benefits to the local population. [35] addressed the SA of hydropower projects in Switzerland, without considering technological attributes. Instead, they use the ecological impacts, job creation, and distributional justice through tax collection. They also include plant ownership (local, national private, and international private) and procedural justice as public involvement in the decision-making and planning process for a hydropower plant, ranging from low (information brochures) to high levels of participation (referendums). [53] analyzed the SA of alpine solar power projects. The authors represented technological attributes through the design of the solar photovoltaic project, using either conventional solar panels, green solar panels, or artistic elements (animal design or Swiss flag design). They also include the impacts on the surrounding ecosystem as an ecological attribute and plant ownership, including local, international, and a combination of operators. Regarding distributional justice, the range goes from "hardly any local financial benefits" to a "municipal benefit via solar tax." In contrast, procedural justice includes legally required information events. [50] assessed the acceptance levels of renewable projects (photovoltaic and wind) in South Korea using subsidies as a distributional justice attribute. This case was further developed in a broader sense by assessing the SA of the transition policy [37].

Two studies on renewable marine energy have been conducted. On the one hand, [46] studied the construction of a tidal plant on the west coast of South Korea. The authors use price as a distributional justice attribute and three ecological attributes: the reduction in the area of tidal flats, degree of degradation of seawater, and degree of destruction in marine life. All three situations are compared to the current levels.

On the other hand, [47] applied a DCE to Ria de Ribadeo, Spain, to investigate the public perception and monetary value of the externalities associated with a tidal stream farm. The study considered three ecological attributes: avoiding CO_2 emissions by using tidal instead of another energy source, loss in marine life, and reduced marine water quality. The authors also used two socioeconomic attributes–employment and tourism–and two distributional justice attributes–economic compensation and taxes.

Table 1. Main Attributes Used in Community Acceptance Assessment

Authors	Country	RES	Attribute Type	Attributes Used	Energy-Mix
[54]	Greece	Wind	✓ Technological ✓ Ecological ✓ Procedural Justice ✓ Distributional Justice	✓ Wind farm size ✓ Height; Natural area proximity ✓ Deliberation ✓ Subsidy	Fossil-Fuels: 87% Hydropower: 9% Solar and Wind:4%
[46]	South Korea	Tidal	✓ Ecological ✓ Distributional Justice	✓ Reduction in tidal flats, Degradation of seawater quality, and marine life destruction. ✓ Additional income tax to reduce environmental damages.	Fossil-Fuels: 66% Hydropower: 0,7% Nuclear: 33% Solar and Wind: 0,3%
[52]	Italy	Wind	✓ Technological ✓ Ecological ✓ Socioeconomic ✓ Distributional Justice	✓ Power generation ✓ Aesthetic impact; CO2 emission reduction ✓ Job creation ✓ Services to the local population	Fossil-Fuels: 61% Hydropower: 16% Solar and Wind: 14%
[47]	Spain	Tidal	✓ Ecological ✓ Socioeconomic ✓ Distributional Justice	✓ Avoided CO2 emissions; displacement of marine life; reduction in marine water quality ✓ Employment; effect on tourism. ✓ Economic compensation to the local community; additional tax per household.	Fossil-Fuels: 44% Hydropower: 10% Nuclear: 21% Solar and Wind: 23%

[49]	France	Wind	✓ Technological ✓ Distributional Justice	✓ Existence of offshore wind farms ✓ Recreational activities associated with the wind farm; impact mitigation; change in the accommodation price for tourists.	Fossil-Fuels: 7% Hydropower: 10% Nuclear: 76% Solar and Wind: 5%
[48]	Norway	Wind	✓ Ecological ✓ Distributional Justice	✓ Visual impact ✓ Electricity bill rebate; Sports facilities	Fossil-Fuels: 2% Hydropower: 96% Solar and Wind: 1%
[55]	France	Wind	✓ Distributional Justice	✓ Scallop reseeding; Cleaning sea bottom; Creation of feeding areas for bird life; artificial reefs; Facilities for observation of plants and animals; Recreational Facilities; Funding chilled tanks for lobsters; Subsidies to local communities	Fossil-Fuels: 10% Hydropower: 11% Nuclear: 72% Solar and Wind: 5%
[35]	Switzerland	Hydropower	✓ Ecological ✓ Procedural Justice ✓ Socioeconomic ✓ Distributional Justice ✓ Ownership	✓ Ecological impact ✓ Public participation ✓ Employment ✓ Income from water tax ✓ Owner of the plant	Fossil-Fuels: 6% Hydropower: 56% Nuclear: 34% Solar and Wind: 3%
[56]	Lithuania	Solar	✓ Socioeconomic ✓ Ecological ✓ Distributional Justice	✓ Installation costs; Monthly bill; Length of the warranty period ✓ Requirements for operation ✓ Sharing energy produced	Fossil-Fuels: 20% Hydropower: 16% Solar and Wind: 45%
[51]	Germany	Wind	✓ Procedural Justice	✓ Participation and decision power	Fossil-Fuels: 70%

			✓ Distributional Justice ✓ Ownership	✓ Shareholding; change in electricity bill ✓ Owner of the plant	Hydropower: 11% Solar and Wind: 19%
[50]	South Korea	Solar and Wind	✓ Technological ✓ Ecological ✓ Procedural Justice ✓ Distributional Justice	✓ Power Capacity ✓ Distance from residence; location ✓ Partner type ✓ Subsidy	Fossil-Fuels: 66% Hydropower: 0,7% Nuclear: 28% Solar and Wind: 4%
[53]	Switzerlan d	Solar	✓ Ownership ✓ Ecological ✓ Distributional Justice ✓ Procedural Justice ✓ Technological	✓ Ownership ✓ Ecological impact ✓ Benefits sharing ✓ Participation and decision power ✓ Design of the solar PV project	Fossil-Fuels: 4% Hydropower: 61% Nuclear: 30% Solar and Wind: 5%

Source: Energy-mix: [57]

3. Chilean Marine-Energy Sector

Chile's RES potential has been growing in the last decade, increasing from 37% in 2010, primarily based on hydropower, to 48.7% of the National Electric System (NES) generation capacity in 2019. In this context, renewable energy has become Chile's primary electricity source [58]. Although this has grown significantly, MES is predominant within the energy mix. For example, in 2020, the generation capacity of RES was 13,412 MW of the NES (51% of the generation capacity), of which hydropower represented 50.8%, followed by solar (26.6%), wind (18.8%), biomass (3.4%), and geothermal (0.33%) [59]. In 2021, the EES became part of the NES with the inauguration of the first concentrated solar plant in Latin America, in the Atacama Desert. Regarding tidal energy sources, since April 2021, the Marine Research and Innovation Center (MERIC) has been testing in Central Chile a power buoy (PB3) 13 meters in length, which is the first wave energy converter on a real scale in Latin America. However, EES are still underdeveloped in Chile despite its enormous potential for energy generation.

The long coastal extension of approximately 4,300 km makes Chile an ideal place to take advantage of marine energy sources such as waves or tides. According to [60], the potential wave energy is 240 GW, whereas other reports estimate that the potential for tidal generation is more than 160 GW [61]. Furthermore, Chile has clear advantages as a marine energy source over other RES. Chile's marine energy density (kW/m2) is much larger than conventional RESs such as solar or wind. For example, solar and wind in Chile produce less than 5 kW/m2 daily, waves go from 20 to 50 kW/m2 per day, and tidal can reach 30 kW/m2 daily depending on the location [60]. The main disadvantage of tidal energy generation is its variation during the day, similar to that of solar energy generation, which ranges from zero to its maximum potential. In contrast, wave energy density remains stable during the day. Consequently, the capacity factor (variability in production over time) for wave energy is 50%, and that for tidal energy is 30%. This percentage is similar to that of other technologies in Chile, that is solar power at 25% and hydropower at approximately 50% [60].

RES in Chile is spatially differentiated owing to market and technological conditions. Solar and wind plants are located in the northern zone, whereas hydropower plants are located in the central and southern zones [59]. The marine energy potential follows this spatially differentiated pattern, where the wave potential is more significant in the central and northern zones, and the conditions for tidal energy plants are better in the southern zone [60]. However, this distribution pattern could disadvantage the development of tidal energy sources in Chile because electricity demand is mainly located in the central and northern zones [59].

Production cost reductions and regulatory changes have underpinned Chile's RES growth. RES production costs have significantly decreased over the last decade. For instance, the global weighted average of the levelized cost of energy for photovoltaics went from 0.381 USD in 2010 to 0.057 USD per kWh in 2020. Similarly, the cost of concentrated solar power went from 0.34 USD in 2010 to 0.108 USD per kWh in 2020 [62]. These cost reductions probably drive significant changes in Chilean energy generation technologies. Estimations suggest that the cost per kWh of waves is around 0.3 USD and for tides is around 0.2 USD, in Chile [60]. Incentives from the public sector have boosted the increasing introduction of RES. In 2012, the National Energy Strategy clearly stated a path for promoting new energy sources by focusing on renewable sources. The document established the pillars of Chile's energy policy, one of which is a non-conventional new renewable source (NCRES). This policy was implemented through a law that defined a goal of 10% of NCRES by 2024 [63]. In 2015, under the new administration, the government expanded its time horizon to focus on the year 2050. This new strategy corrects the goals of the National Energy Strategy, considering the initial successes, and proposes new objectives from now to 2050 [64]. Thus, although mainstream RES dominated the first decade, Chilean policy had no limitation on developing a particular RES. In this context, marine energy can be part of the renewable mix of energy sources in the coming years.

4. Methodology

4.1 Experimental design

We applied the survey to an online panel provided by the survey company IPSOS, collecting 480 observations in June 2020. Respondents were required to be aged 18 years or older. Furthermore, we applied other filters to their residential zones, selecting only those in the central and southern regions. Finally, for convenience, we divided the sample equally between men and women and between the central and southern zones, yielding 120 observations for each category (women-center, women-southern, men-center, and men-southern).

The design of the final survey followed two steps: 1) forming focus groups to explore how people react to specific aspects of the hypothetical scenario and identify wording problems or misleading sections in the survey (four focus groups, five people each), and 2) conducting pilot surveys to field-test the design of the instrument (20 surveys). These pilot surveys were conducted face-to-face in the southern zone (Concepción).

The questionnaire consisted of five parts with approximately 25 questions. The first part started with an animated recruitment video (33 seconds) to inform the interviewee about the study's objective and the survey's general context. Subsequently, through close-ended questions, we collected general information about the interviewees (gender, age, household size, educational level, and income), previous knowledge of marine energy, and household expenditures on electricity. Using an animated video (1:25 min), the second part provided the general choice context, including the context of marine energy generation (technology, current state of development in Chile) and potential negative impacts (energy production, visual impact, and seabed impact). Next, the potential positive effects (job creation, property rights, compensation to the community, and individual compensation) were presented using text. We followed this dual approach (animated video and text) to explain the choice context and kept the video within a reasonable length to keep the interviewees' attention. An animated video (1:09 min) with an example of the choice set was presented in the third section, whereas the fourth section presented different choice options (details about the video content in Appendix A). The final section addressed attitudinal questions regarding the attributes of energy projects.

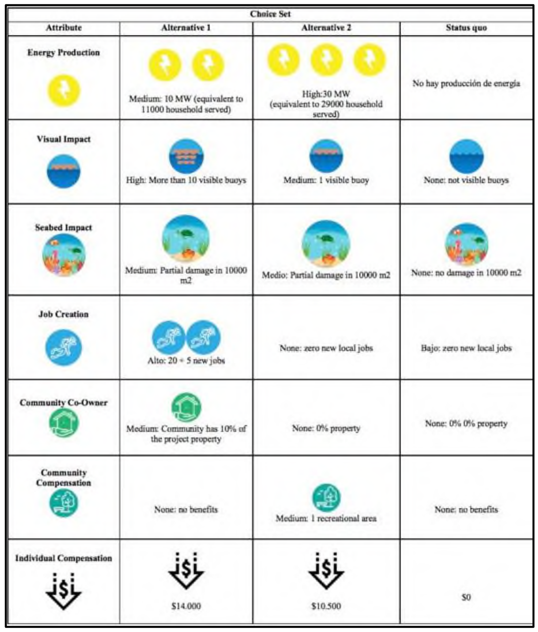
In line with the mainstream literature, we characterized marine energy project development using five attributes: technological, ecological, socioeconomic, ownership, and distributional justice. Furthermore, we added to the current literature by jointly assessing two different distributional justice attributes (individual and social). Technological attributes were represented by the energy production capacity of the project, which depended on the buoy extension. To facilitate this understanding, we presented energy generation in terms of households served. The ecological attributes included the project's potential impact on the landscape (visual impact) and seabed. In the first case, the effect depends on the buoy density, whereas the impact of the seabed depends on the installed capacity. We used job creation as a socioeconomic attribute; the new jobs were associated with local divers for project construction or implementation. The ownership attribute implies that the community is the project co-owner. Finally, the distributional justice attributes included two dimensions: a) community compensation, implying the construction of different community-oriented facilities, and b) individual compensation through a ten-year reduction in the electricity bill. Table 2 presents the details of the attributes and levels used.

Table 2. Description of attributes and levels

Attributes Type	**Attribute Name**	**Levels**
Technological	Energy Production	✓ None (no energy generation) ✓ Low (3 MW, equivalent to 1,000 households served) ✓ Medium (10 MW, equivalent to 11,000 households served) ✓ High (30 MW, equivalent to 29,000 households served)
Ecological	Visual impact	✓ None (not visible buoys) ✓ Medium (1 visible buoy) ✓ High (more than 10 visible buoys)
	Seabed impact	✓ None (no damage in 10,000 m2) ✓ Medium (partial damage in 10,000 m2) ✓ High (massive damage in 10,000 m2)
Socioeconomic	Job creation	✓ None (zero new local jobs) ✓ Medium (10 new jobs for local divers during the project construction stage -1 year). ✓ High (20 new jobs for local divers during the project construction stage -1 year, and 5 new jobs for local divers during the project implementation stage -5 years).
Ownership	Community co-owner	✓ None (community does not participate in the project property) ✓ Medium (the community has 10% of the project property)

		✓ High (the community has 45% of the project property)
Distributional Justice	Community Compensation	✓ None (no community-oriented facilities) ✓ Medium (1 recreational area, including green areas and kids-play zone, 1000 m2) ✓ High (1 recreational area, including green areas and kids-play zone, 1000 m2; and 1 dock for boats smaller than 12 mt)
	Individual Compensation	✓ None (no decrease in the electricity bill) ✓ \$3,500 decrease in the electricity bill ✓ \$7,000 decrease in the electricity bill ✓ \$10,500 decrease in the electricity bill ✓ \$14,000 decrease in the electricity bill

We followed an optimal experimental design suggested by [65] that selected the combination of attributes that minimized the variance of the coefficients [66] using NGENE. Furthermore, efficient designs allowed us to balance the desired properties of orthogonality, level balance, and utility balance [67]. As we included six choice sets per questionnaire, we obtained 2,880 observations. This sample size was adequate considering that, for choice experiments, [68] and [69] suggested a minimum sample size of $\mathrm{N} = 480 * \frac{\mathrm{NLEV}}{\mathrm{NALT} * \mathrm{NREP}}$, where NLEV (6 in our case) is the largest number of levels in any attribute, NALT (3) is the number of alternatives per choice set, and NREP (3) is the number of choice questions in the survey (N=320). An example of a choice set is shown in Figure 1.



Choice Set			
Attribute	Alternative 1	Alternative 2	Status quo
Energy Production	Medium: 10 MW (equivalent to 11000 household served)	High:30 MW (equivalent to 29000 household served)	No hay producción de energía
Visual Impact	High: More than 10 visible buoys	Medium: 1 visible buoy	None: not visible buoys
Seabed Impact	Medium: Partial damage in 10000 m2	Medio: Partial damage in 10000 m2	None: no damage in 10000 m2
Job Creation	Alto: 20 + 5 new jobs	None: zero new local jobs	Bajo: zero new local jobs
Community Co-Owner	Medium: Community has 10% of the project property	None: 0% property	None: 0% 0% property
Community Compensation	None: no benefits	Medium: 1 recreational area	None: no benefits
Individual Compensation	$14.000	$10.500	$0

Figure 1. Choice Set Example

4.2 Discrete Choice Model

The DCE is a flexible methodology for eliciting individual preferences. It is based on a random utility model (RUM) framework that models consumer decisions among a set of finite and mutually exclusive alternatives. Formally, individual *n* chooses alternative *i* only if the utility provided by this alternative is greater than that of all the other *J* alternatives [70]. The utility associated with alternative *i* for the individual *n* can be decomposed in a deterministic and observed component (V_{in}) and a stochastic and non-observable component (ε_{in}):

$$U_{in} = V_{in} + \varepsilon_{in} \qquad n = 1, \dots, N, \; i = 1, \dots, I \tag{1}$$

Assuming that V_{in} is linear and ε_{in} is distributed identically and independently (IID) according to a type I extreme value distribution, we can obtain the most common RUM known as the multinomial logit model (MNL). Alternatively, we can explore the discrete unobserved heterogeneity through a latent class (LC) model, which assumes that individuals are heterogeneously distributed in a population and can be distributed into *Q* finite latent classes where each *n* individual has a $\pi_{n,q}$ probability of belonging to class q. Moreover, the individuals share common β_q parameters within the class but can differ across classes. An extension of LC models is to allow the class allocation probability ($\pi_{n,q}$) to follow a logit structure which permits us to link z_n sociodemographic variables to the class allocation. In this model, an individual's *n* probability of belonging to class *q* is given by

$$\pi_{n,q}(\theta) = \frac{exp(\theta_q z_n)}{\sum_{q=1}^{Q} exp\,(\theta_q z_n)} \tag{2}$$

Moreover, the conditional probability that individual *n* chooses alternative *i* is:

$$P_{n,i}(\beta_q) = \frac{exp(V_{in})}{\sum_{j=1}^{J} exp\,(V_{jn})} \tag{3}$$

$$V_{in} = \beta_q SQ + \sum_{k=1}^{K} \beta_q x_{ikn} \tag{4}$$

where x_{ikn} are the *k* different attributes presented in the DCE (Table 1) and SQ refers to a status-quo alternative specific constant, which implies that it does not support the new energy generation project.

5. Results

5.1 Estimation results

Descriptive statistics show that our sample is balanced in terms of sex and geographical location. In addition, they are highly educated and had some knowledge of marine energy. Our respondents' high level of education is a common feature of online panels provided by professional enterprises, such as IPSOS (Table 3).

Table 3. Descriptive Statistics

Variables	Mean	Standard deviation	Minimum	Maximum
Gender (1 = Male)	0.50	0.50	0	1
Age (1 = older than 40)	0.46	0.50	0	1
Tertiary education (1= attended or finished tertiary education)	0.73	0.44	0	1
Marine energy knowledge (1= Have heard about them)	0.53	0.50	0	1
Southern zones (1 = if individual belongs to Biobio or Los Lagos region)	0.50	0.50	0	1

Starting with MNL (third column in Table 4), the first result indicates that the current situation is positively valued and statistically significant, implying that individuals do not accept the development of new marine energy generation projects, as expressed by the positive sign of the SQASC parameter. Using the same model, it is possible to identify the attributes that can foster the SA of marine energy projects. For instance, results by attribute type show that technological attribute (energy production) is preferred (and statistically significant) by the interviewees, and the same result is reported for the socioeconomic attribute of job creation, meaning that in both cases, projects with higher energy generation and job creation will have a higher SA. Both distributional justice attributes are valued and statistically significant. Thus, projects, including community and individual compensation schemes, will have higher levels of SA. In contrast, the larger the ecological impact, either visually or at the seabed, the lower is the project SA (as the parameters are negative and statistically significant). Interestingly, including the community as a project co-owner did not affect the project's SA.

As previously mentioned, the SA level of energy projects can differ among individuals within the same area. Therefore, policymakers and energy producers should consider these preferences when developing marine energy projects to ensure that they are more acceptable to individuals and meet their needs better. In the LC model, we decided to constrain our analysis to two classes: class 1 (status-quo supporters), which may be individuals who are risk-averse and therefore more likely to stick with what they know, and class 2 (emerging energy source supporters), which may be individuals who are open to new energy developments and are therefore more likely to consider alternative options.

Table 4. Estimation results

Type	**Mean**	MNL	LC	
			Class 1	Class 2
		Mean (Rob. Std.err)	Mean (Rob. Std.err)	Mean (Rob. Std.err)
	Status quo ASC (SQASC)	0.3554** (0.1258)	1.2207*** (0.2765)	-1.6005*** (0.2845)
Technological	Energy production	0.1621*** (0.0319)	0.1424^{+} (0.0823)	0.1937*** (0.0376)
Ecological	Visual impact	-0.1480*** (0.0374)	-0.1965 (0.1341)	-0.2008*** (0.0455)
	Seabed impact	-0.2006*** (0.0392)	-0.5116*** (0.1716)	-0.1568*** (0.0435)
Socioeconomic	Job creation	0.2086*** (0.0316)	-0.0171 (0.0945)	0.2995*** (0.0407)
Ownership	Community co-owner	0.0303 (0.0294)	-0.3751*** (0.1039)	0.1190*** (0.0342)
Distributional Justice	Community Compensation	0.1768*** (0.0279)	-0.1066 (0.0885)	0.2487*** (0.0336)
	Individual compensation	0.0001*** (0.0000)	0.0001*** (0.0000)	0.0001*** (0.0000)
Class allocation				
Constant		-	-	-0.9694*** (0.2968)
Male		-	-	-0.7147** (0.2252)
Older than 40		-	-	-0.2593 (0.2233)

Tertiary education	-	-	-0.7843*** (0.2808)
Marine energy knowledge	-	-	-0.3527 (0.2228)
Class membership probability		0.2711	0.7289
AIC	5798.3	4879	
BIC	5846.02	5004	
Log-likelihood	-2891.15	-2419	

Status-Quo Supporters (SQS, class 1) account for 27% of our sample and have the same positive preferences for current status as the whole sample (represented by the MNL model). Additionally, similar to the entire sample, these individuals' SA is fostered by technological attributes (energy production). However, unlike the whole sample, the SA of SQS is fostered by only one distributional justice attribute (individual compensation). In contrast, the other (community compensation) does not affect SA of marine energy projects. Regarding ecological attributes, only seabed impacts hinder SA levels in these individuals. Unlike the whole sample, community co-ownership hinders the SA of marine energy projects, whereas socioeconomic attributes do not affect SA.

Emerging energy source supporters (EESS, class 2) represent the largest share of the sample (73%) and show a stronger preference for accepting marine energy projects. Despite this difference, their preferences regarding specific attributes are similar to those of the whole sample, with technological and socioeconomic attributes fostering SA. The same result holds for both distributional justice attributes (community and individual compensation). Similar to the entire sample, the SA of these individuals is negatively affected by both ecological attributes. Interestingly, the results show that the SA of these individuals is positively affected by community co-ownership.

The LC model also allows us to estimate a class allocation model, whose estimated parameters describe how different variables affect the likelihood of belonging to one class or another. We included the explanatory variables of sex, age, tertiary education, and knowledge of marine energies. Moreover, for identification purposes, we fix the estimated parameters to class 1. Thus, the estimated parameters indicate that women, individuals with tertiary education and/or high marine energy knowledge, may have a higher probability of belonging to the EESS class, which is characterized by higher levels of support for marine energy projects.

As previously mentioned, one of the main differences between the two classes is related to their general preferences for marine energy projects. Other differences are related to preferences regarding socioeconomic and community compensation attributes (in both cases, it fosters the SA of individuals within the EESS class, whereas it does not affect the SA of SQS). Another relevant difference among the classes is related to community co-ownership. For EESS, community co-ownership is expected to foster the SA, whereas for SQS, community co-ownership is expected to hinder SA. This difference could be due to various reasons such as a lack of trust in community management or a preference for private ownership.

5.2 Attribute Preferences

We asked individuals to order the marine energy project attributes according to their preferences using a Likert scale (1 = not important to 7 = very important). Our results (Figure 2) show that the most important attributes of the general sample (MNL) are seabed impact and energy production. In contrast, community ownership and individual compensation seem unimportant to the respondents.

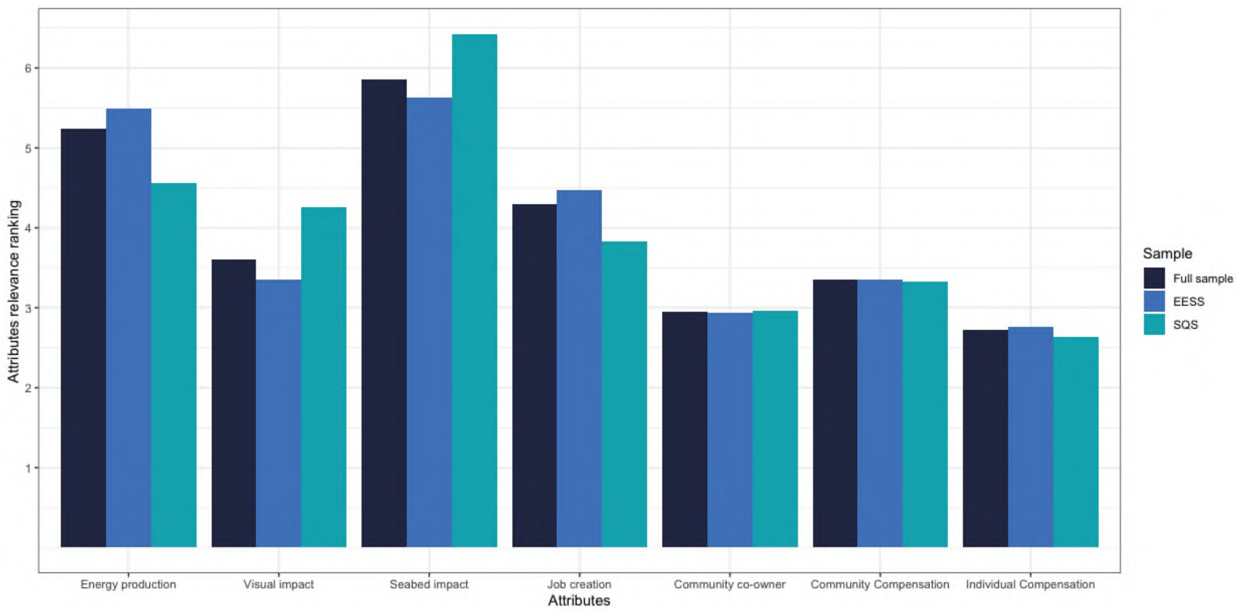


Figure 2. Attributes Ranking

Despite having a similar order, the two classes have different preferences for the proposed attributes (Figure 2). For instance, individuals within the SQS class seem to place more importance on seabed impacts than those within the EESS class. The same applies to energy production. For both classes, the attributes related to distributional justice (community and individual compensation) seem to have the same relevance, with community compensation being more relevant than individual compensation.

Using the mean willingness to accept (MWTA), we can contrast what people say about their preferences with what people would do when confronted with the marine energy project. Using the MWTA, we found that the most relevant attribute for the whole sample was job creation, followed by community compensation (Figure 3). However, ecological attributes were less important. These results indicate that what people declare differs from what they would do when facing a marine energy project.

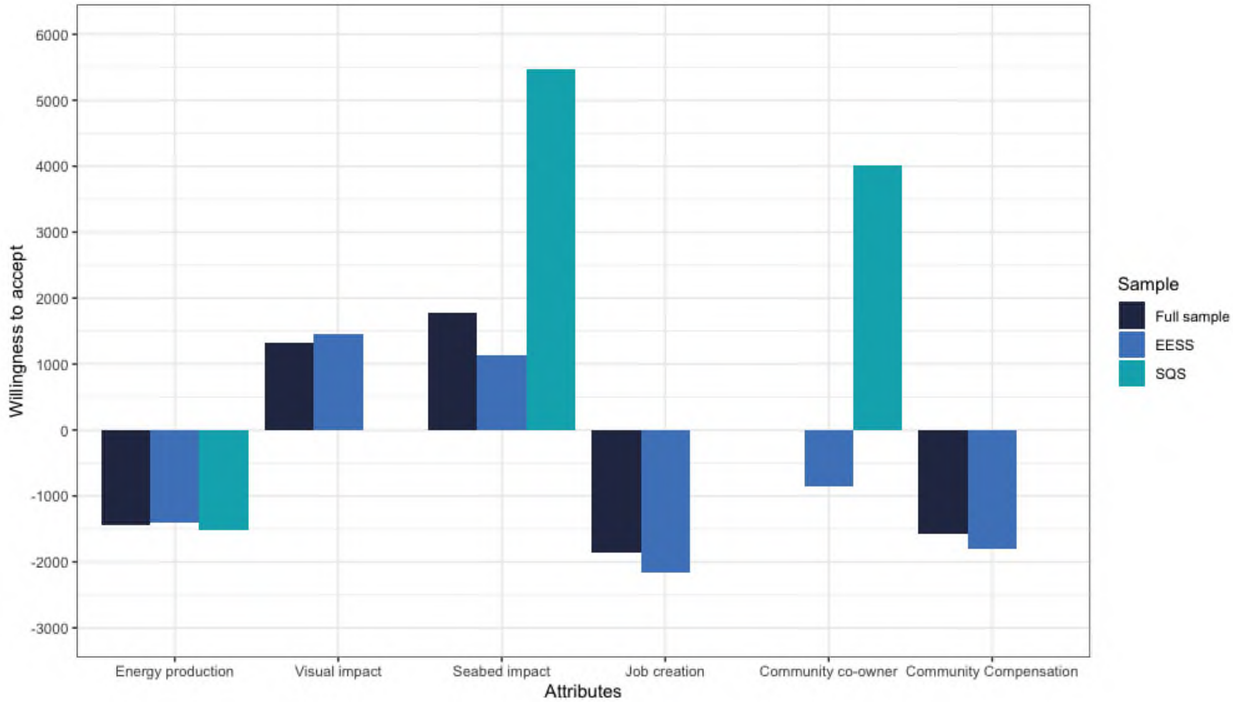


Figure 3. Marginal Willingness to Accept (MWTA).

For the SQS class, the most relevant attribute is energy production, and people in this class require significant compensation to accept a project with community co-ownership. Individuals in the SQS class are willing to pay to avoid a project under this governance scheme, which suggests a strong preference for a free-market solution. In contrast, for the EESS class, community co-ownership is the third most relevant attribute behind job creation and community compensation.

6. Discussions and Conclusions

In this study, we assess the main attributes determining the SA of marine energy projects, highlighting the heterogeneity of individual preferences for these projects. In general, we found that technological, socioeconomic, and distributional justice parameters increase the SA of renewable marine energy projects, whereas ecological attributes decrease the SA. However, individual preferences are highly heterogeneous, with two classes having well-defined and opposing preferences for marine projects. We hypothesize that our results may depend on the respondent's level of knowledge of marine energy, which, is slightly higher than that reported in Europe [40].

Interestingly, our aggregated results (MNL model) show that respondents strongly prefer the status quo and do not accept the development of renewable marine energy projects. This situation could be explained by the high perceived risk, mainly influenced by relatively low knowledge of this type of project. Considering the transformative potential of renewable marine energy, we need a better understanding of stakeholder attitudes toward decreasing perceived risks, which may increase project acceptance [9].

Our results, in general and for both classes, show that energy production increases SA. Previous evidence related to wind energy has shown negative or nonsignificant [54] impacts [52] of this attribute. However, for marine energy projects, [47] a positive relationship was found between the SA and avoided CO_2 emissions, which could be associated with the size of the energy project. Similar to most previous evidence, our results show that ecological impacts are negatively related to project SA. Similar results are obtained for wind energy projects [50,52–54], solar [50], hydropower [35], and tidal energy projects [46,47]. Regarding socioeconomic attributes (job creation), our results show a positive effect on SA, similar to previous evidence related to tidal [47], wind [52], and hydropower projects [35].

The SA of an individual willing to accept a marine energy project is positively affected by the community ownership of the project. Similar results are reported for the assessment of wind projects in Germany [51], in which the SA increases when a community can buy project shares. We find that distributional justice parameters increase the SA of marine projects. Similar results for individual compensation were found by [54] for wind projects in Greece and by [50] for solar and wind projects in South Korea, whereas for community compensation, the same results were reported by [47] for tidal projects in Spain, by [52] for wind projects in Italy, and by [48] for wind projects in Norway.

Analysis at the attribute level shows that the most relevant attributes are job creation (MNL and EESS) and energy production (SQS), with distributional justice attributes (individual compensation) ranking second for MNL and EESS. Furthermore, we found a mismatch between what people say and what they would do when facing a marine energy project. Our results suggest that when people order their preferences for specific attributes without facing a trade-off (i.e., monetary expenditure), they are more concerned about the ecological aspects of the project. However, when people's decisions imply a monetary trade-off, their preferences tend to privilege private benefits (i.e., job creation).

Based on our results, we suggest that policymakers and energy producers should consider the preferences of different groups of individuals when designing energy projects in general and marine energy projects in particular. In line with previous evidence regarding wind generation [18] and solar and biomass projects [20], we identified heterogeneous preferences for renewable marine projects among the respondents. In our case, the main differences between the two classes were related to general preferences for marine energy projects, the preferences regarding socioeconomic attributes, community compensation attributes, and community co-ownership. In the present study, both classes had similar ecological attribute preferences. Our results differ from those of [55], who also identified two distinct classes in which class membership depended only on naturalist recreational activity. This contrasting result indicates that a one-size-fits-all approach may be inappropriate. Instead, policymakers and energy producers should tailor their proposals to meet the needs of different groups, considering their preferences and concerns. Failing to do so may lead to the overlooking of important factors that could lead to opposition and resistance in some groups [11]. This could result in delays, legal challenges, or project cancellations, which could be expensive in terms of time and resources.

For individuals within the SQS class, compensation at the individual level is more important than that at the community level. Consequently, they are less likely to support community ownership of marine energy projects. Policymakers and energy producers should consider this when designing compensation schemes for marine energy projects to ensure that they adequately compensate individuals who may be negatively impacted by the project. In contrast, individuals in the EESS class strongly prefer marine energy projects and are more likely to support community ownership. Policymakers and energy producers should consider this preference for community ownership when designing projects, as it may enhance the social acceptability of the project.

Furthermore, the relevance of community ownership in fostering SA of marine energy projects for the most significant class highlights the governance challenges that this project may face. Effective governance in the marine energy sector is not confined to conventional hierarchical models. It requires an inclusive, participatory approach that builds trust, guarantees transparency, and enables fair distribution of benefits [71]. Furthermore, the governance model should be flexible enough to meet the unique needs of different stakeholders, who are sometimes in conflict, and should be in harmony with the broader objectives of environmental sustainability and the transition to a low-carbon economy [72].

The results also suggest that females and individuals with tertiary education may have a higher probability of belonging to the EESS class, which is characterized by higher levels of support for marine energy projects. Therefore, policymakers and energy producers should focus on educating the public and increasing awareness of the benefits of marine energy, especially among those who are less knowledgeable about it. Overall, the results of this study highlight the importance of understanding the preferences of different groups of individuals when designing renewable energy projects. By considering these preferences and concerns, policymakers and energy producers can increase the social acceptability of marine energy projects and ensure that they are sustainable and effective over the long term.

Similar to other empirical studies, our study has limitations that could illuminate avenues for future research. First, in the DCE design, we did not consider the energy mix as an attribute that explains community acceptance of the marine project. Following [37], we believe that future research could delve into this point as it makes explicit the current substitution options for different energy sources. Second, our study focuses on assessing the community acceptance of a single project. An extension of our work could include the joint assessment of different renewable projects (i.e., tidal and offshore winds), thus better explaining the trade-offs faced by the respondents. Third, to select our sample of respondents, we relied on an online panel of interviews, which is a specific population subsample that does not represent the preferences of older individuals, rural communities, or hard-to-reach stakeholders (e.g., environmentalist leaders). Moreover, the DCE has limitations in understanding the complex preferences of essential stakeholders. Therefore, future research should complement these results using qualitative or participatory methods, focusing on the previously mentioned subsamples. Finally, the respondents were exposed to different videos to explain their choice scenarios. Other researchers could expand this approach by implementing choice scenarios based on virtual reality to provide a more comprehensive description of the different attributes and trade-offs across them.

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<u>Appendix A: Video's Main Messages</u>

1. **Recruitment Section (length: 33 seconds):** In this section, we presented the respondents with the general survey, informing them about the general objective. Some of the information provided includes:
   - "In this survey, we are interested in knowing your perception about renewable energy generation projects using the energy of the sea."
   - "We would like to know your opinion on the positive and negative aspects of this type of project."
   - "Your opinions are confidential and will be used as fundamental information for a research project, which could be used to design the country's energy policy."

	
a) In this survey, we are interested in knowing your perception of renewable energy generation projects using the energy of the sea	b)We would like to know your opinion on the positive and negative aspects of this type of project
	
c) Your opinions are confidential.	d) The results of this study may inform Chile's energy policy development.

Figure A.1: Screenshots Recruitment Section

2. **Choice Context (length: 33 seconds):** This section provides the general choice context, including the context of the marine energy generation (technology, current state of development in Chile) and the potential negative impacts (energy production, visual impact, seabed impact). Some of the information provided includes:
    - "Tidal energy generation is a type of renewable energy that can be generated using tidal action; this energy can be generated using floating or submersible devices on the coast or offshore. It is through the movement of these devices that energy is generated."
    - "In Chile, wave generation is in the pilot stage, with experiences in Antofagasta and Valparaíso."
    - We will present some characteristics of this type of energy. Generation. The level of generation will depend on the extension of the buoy.
      a) Low: 3 MW (could supply 1,000 homes)
      b) Average: 10 MW (could supply 11,000 homes)
      c) high: 30 MW (could supply 29,000 homes)
    - Visual impact. Depending on the density of buoys, they could have a visual impact.
      a) Low: no visual impact
      b) Medium: it is possible to observe 1 buoy
      c) High: it is possible to observe 10 buoys

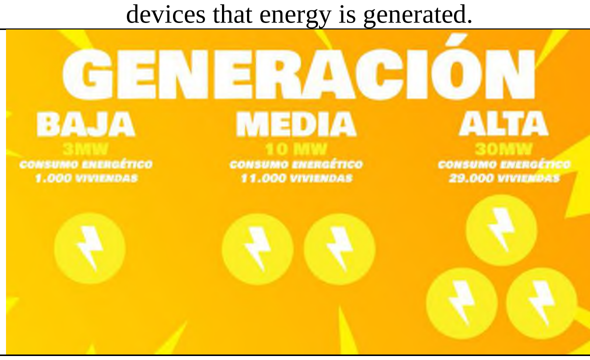
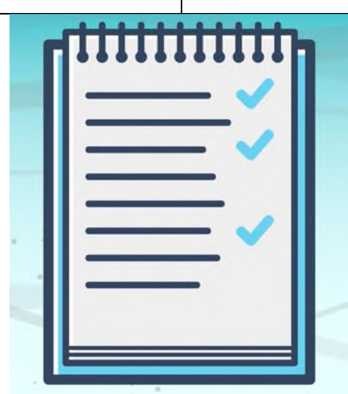
<table>
<tr><td>
</td><td>
</td></tr>
<tr><td>a) Tidal energy generation is a type of renewable energy that can be generated using tidal action; this energy can be generated using floating or submersible devices on the coast or offshore. It is through the movement of these devices that energy is generated.</td><td>b) In Chile, wave generation is in the pilot stage, with experiences in Antofagasta and Valparaíso.</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>c) Generation. The level of generation will depend on the extension of the buoy (low, medium, high)</td><td>d) Visual impact. Depending on the density of buoys, they could have a visual impact (low, medium, high).</td></tr>
</table>

Figure A.2: Screenshots Choice Context Section

3. **Choice Set (length 1:09 minutes):** In this section, we presented an animated video with an example of the choice set. Some of the information provided includes:
   - "We want your opinion about different energy generation options."
   - "This scenario has three options. The first involves maintaining the current situation; it does not consider changes. The other two options differ in their medium and high generation levels; in their high and medium visual impact; impact on the seabed both with medium impact; high and low level of jobs; medium and low property rights; low and medium community compensation; and the individual compensation level of $14,000 and $10,500 respectively.
   - Some people interviewed previously have chosen alternative 1 or 2, while others prefer to stay as they were. All of these opinions are equally valid. Remember that there are no right or wrong answers.

a) We want your opinion about different energy generation options.

b) Scenario options, attributes, and levels.



c) Some people interviewed previously have chosen alternative 1 or 2, while others prefer to stay as they were. All these opinions are equally valid; remember that there are no right or wrong answers.

Figure A.3: Screenshots Choice Set Section